Project NY 500 002-7

Final Technical Memorandum M-081

3 April 1953

DESIGN, DEVELOPMENT AND EVALUATION OF A 25-FT BY 48-FT, DISASTER SHELTER

W. R. Mason and J. E. Schroeder

U. S. Naval Civil Engineering Research and Evaluation Laboratory
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SUMMARY

The 25-ft by 48-ft Disaster Shelter was designed, developed, and evaluated at the Laboratory to fulfill the need for emergency shelter in the event of a major disaster. The design and development included a close analysis and revision of the existing criteria and thorough studies of materials. The evaluation included erection studies, weathertightness tests, and structural tests to determine its adequacy for withstanding the specified loads.

It was found from these tests that the building was structurally adequate, both simple and rapid to erect, essentially weathertight, and economical in cost and use of materials.

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INTRODUCTION

To facilitate the provision of minimum shelter for military personnel and civilians in the event of a major natural or man-made disaster, a need exists for a structure that is economical in cost, easily produced, economical in the use of critical materials, easily and rapidly erected by unskilled labor and having a minimum useful life of six months. Previous work by the Bureau and the Laboratory on a structure to fulfill this need has consisted of the evaluation of a prefabricated building utilizing a special fabric for covering and investigations of various light frames and covering materials.

This technical memorandum covers the design, development, and evaluation of an A-frame, wooden disaster shelter, see Figure 1. A thorough review of the criteria originally established for this shelter by the Bureau, Appendix I, was made prior to the design. The design was accomplished through the coordinated efforts of the Laboratory and Harold P. King, Structural Engineer, under contract. Tests to determine the ease of erection, weathertightness, minimum life, and structural adequacy were conducted at the U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California under Project NY 500 002-7 authorized by the Bureau of Yards and Docks[1].

DESIGN CRITERIA

The original criteria established for disaster shelters is contained in the "Guide Specification for Class 'Z' Structures" (Appendix I) issued by the Bureau of Yards and Docks on 9 August 1950.

A close analysis by the Laboratory of the conditions under which the structure would be used, the purpose of the structure, and the expected life of the structure, indicated that availability of materials and economy should be the principal design criteria. To achieve these characteristics of design, it was necessary that some desirable, but not essential, features of the original criteria be sacrificed. The deviations from the original criteria and the reasons for the changes are given in the following paragraphs.

Size and Shape

Since no floor is to be supplied with the building and therefore the use of 4-ft by 8-ft sheets of plywood used for floor panels in other types of buildings was no consideration, the 20-ft by 48-ft overall dimensions established are not essential providing that approximately the same amount of usable floor space is furnished.

Typical Barracks Arrangement of Double Bunks

The necessity for the typical barracks arrangement of bunks was sacrificed for two reasons: (1) single bunks, folding canvas cots, and domestic style beds will be in equal if not greater supply in the event of a major disaster than double bunks; and (2) an arrangement of double bunks other than typical barracks arrangement would be satisfactory.

<u>Prefabrication</u>

Indications are that prefabricated items stockpiled for use in emergencies are often not needed. Because such items have low salvage value, the practice often results in great loss to the Government. It was considered that prefabrication should be held to a minimum consistent with providing a structure both simple in design and easy to erect by unskilled labor.

It was decided by the Laboratory that the design, which was developed with the intention of minimizing prefabrication, should be limited to the use of materials normally found stocked in large quantities at lumber yards and suppliers of building materials throughout continental United States, thus eliminating special stockpiling. In possible man-made disaster areas, ample materials would probably be available in a 25 to 75 mile radius of the disaster area. Shipment of the materials for the buildings would be both fast and economical because of their compact shipping cube. A possibility exists that an adequate supply of materials in critical areas could be achieved at small cost to the Government by contracts with lumber yards and suppliers of building materials to maintain a minimum inventory of the required materials.

If it is considered an absolute necessity to prefabricate and stockpile, the frames could be prefabricated and stored in lumber yards. Covering materials requiring no fabrication could be stockpiled under the above described minimum inventory plan. Cutting of the material and piece marking could be accomplished by lumber yards or wood working shops immediately prior to shipment to the disaster area with little loss in time.

DESIGN

In view of the above considerations and changes to the established criteria, the shelter shown in the design drawings[2] was arrived at from the following considerations:

(a) There are only three basic building elevations: (1) arch rib, (2) rectangular (gabled roof, flat or shed roof with straight sidewalls), and (3) triangular[3]. The arch was never given consideration because of the difficulty of economically producing an arched shaped frame. The rectangular elevation possibilities were seriously studied in view of the double bunk arrangement, but were dropped from consideration for the following reasons:

(1) It is difficult to achieve weathertight joints even with the extensive use of mastics and battens because of the flat pitch

of the roof.

(2) A vertical wall building is not easily adapted to sloping or uneven ground.

(3) Snow loading becomes a critical problem. Either the design must withstand the snow load or withstand the concentrated loads of men shoveling off the snow.

(4) Structural beam members must either be exceedingly large or be supported with interior columns.

(b) All material in the developed building is readily available in lumber yards. Material shown on the drawings is minimum dimension; i.e., if the detailed material is not available, 2 x 6's can replace the 2 x 4's and 1 x 6's can replace the 1 x 4's, etc. The 16-ft roof rafters may be made by splicing 12-ft and 4-ft members or two 8-ft members or any combination in between. In a disaster area, 1 x 4's and 2 x 4's would probably be available from demolished or damaged buildings. Even if prefabricated, salvage value would be high as only the scabs and less than one foot of the roof rafters would be waste.

(c) The shelter is readily and easily erected on sloping or uneven ground.

(d) Prefabrication is held to a minimum, yet field assembly consists only of sawing and nailing. Sawing, with the exception of the angle cut on the roof rafters and the special cuts for the endwall tie to roof rafter scab, consist merely of cutting 1 x 4's and 2 x 4's to length. An investigation of the drawings will reveal that a majority of the members are lengths commonly stocked by lumber yards thus reducing the cutting required. The cuts necessary are made easily with either a handsaw or power equipment.

(e) All nails in the structural framing are No. 8 common which are easily driven by unskilled labor.

(f) Various covering materials may be employed[3]. Materials consistant with local weather conditions are usually available in lumber yards and other suppliers of building materials. In mild climates any building paper or heavy wrapping paper will be satisfactory covering, see Figure 2.

(g) Twenty (20) single bunks, see figure 3, may be placed in the building with a minimum of 2-ft between the bunks and a 6-ft aisle down the center. Twelve (12) double bunks, see figure 4, may be placed in the building with an 18-in. space between groups of two bunks and a 5 1/2-ft aisle down the center. Additional bed space may be obtained when conditions warrant by placing a single bunk between a double bunk and the wall, see Figure 5.

(h) The building may be constructed to any length, either greater or less than the 48-ft shown in the drawings without the resultant excess or shortage of endwalls in prefabricated buildings.

(i) The spacing of the 2 x 4 roof rafters on 2-ft centers results in a structure of greater strength than is required by the criteria. It was felt, however, that common lumber yard stock should be used as long as stresses were not excessive and a two foot spacing of the frames maintained to facilitate the covering with a multiplicity of materials.

DESCRIPTION OF THE BUILDING

The disaster shelter is an all wood, field fabricated, triangular shaped structure that is 25-ft wide, 48-ft long, and 10-ft high at the peak. In consideration of the triangular cross-section of the building, only 18-ft of the width is considered usable floor space. The building may be placed directly on the ground which may be either sloping or uneven without adverse effect on the building.

The building consists primarily of two longitudinal mudsills, 25 A-frames spaced 2-ft on centers, endwall framing and covering material. The mudsills are of 2 x 4's and bear directly on the ground. The A-frames are composed of two 16-ft long legs (roof rafters) of 2 x 4's tied together at the peak with 1 x 4 scabs and with 8-ft long, 1 x 4 collar beams at a point approximately 7-ft above the ground. The base of the legs are cut at an angle for full bearing on the mudsills. One by fours, placed transversely across the building on the ground, are spliced to form mudsill ties and prevent the base of the A-frames from spreading. These A-frames are interconnected to form the frame of the building by horizontal ribbons of 1 x 4's located immediately under the collar beams on the inside face of the roof rafters. Three longitudinal diagonals of 1-in. x 4-in.'s are placed on the inside face of the frames on each side to give the building rigidity. An additional tie is provided at the peak by 1 x 4 ridge ledgers fastened to the outside face of the roof rafters. No. 8 common nails are used to effect all connections.

The endwall framing consists of 2 x 4 vertical studs attached to the endwall A-frame and the endwall mudsill with 1 x 4 scabs. The studs are spaced 2-ft on centers except at the center where a 3-ft space is maintained to provide the door opening.

The covering specified in the drawings is composed of 4-ft by 8-ft rigid panels placed with the long edge along the roof rafters, see table 1 for material required. A six inch lap joint is made at the longitudinal joint between sheets and battens are placed over the butt joints occurring at every other roof rafter. The ridge is covered with a flexible material which may be translucent to provide skylighting.

Access into the building is provided by a 3-ft by 6-ft 5-in. door in each endwall. Natural light is provided by two fixed windows in each endwall and by the ridge covering skylight.

Natural ventilation is achieved by screening the endwall area above the door and providing a removable panel for controlling the air flow. No special provision is made for smokejacks, but the drawings show how commercially available smokejacks may be installed.

TEST PROCEDURE

Two erection studies were made to determine the suitability of the building for assembly under disaster conditions. To simulate these conditions, a team comprised of unskilled labor was used for both erections. In the initial erection study, the material was delivered to the erection site in the standard lumber yard lengths and the pieces were fabricated by cutting with a hand saw. The first erection was observed to determine the ease of erection by unskilled labor, to establish the most efficient size of the erection team, to verify the erectability on uneven ground, to determine the allowable tolerance in the lengths of the members, to determine means of further simplifying the design; and to record the number of manhours required for the erection. Several types and kinds of covering materials were used in this erection to determine those that would be suitable.

The second erection was conducted using all new material and incorporating the design changes and improved erection procedure resulting from the initial erection study. The same team supplemented by two additional men was used in this erection. Covering consisted of rigid boards on one side and flexible covering on the other. Screening was used on one endwall to determine the suitability of this material for use in extremely hot climates. Manhours were again recorded to determine the improved erection time from design and procedure changes and familiarity of the erection team with the building.

Upon completion of both the first and second erection studies, weathertightness tests were conducted by simulating a direct downpour through the use of an overhead sprinkling system. The butt joints were tested with and without battens to determine the necessity of using battens.

Structural tests were made to determine the adequacy of the building to withstand the 60 mph design wind loading stipulated in the criteria. A unit stress of 1450 psi was allowed at the design load for the common lumber used as structural members. Previous tests on frame structures have shown that the strains and deflections occurring in the center portion of the building are independent of the end walls[4]. Because of this knowledge, a part of each end of the building was removed and only a 16-ft center section, which spanned nine of the A-frame assemblies, was used for the simulated wind load. The design wind-loading conditions diagrammed in Figure 6 were applied hydraulically to the roof through pads as shown in Figure 7. The wind load was simulated as supplied through hydraulic cylinders attached to a bent of Navy pontoons. A special hydraulic pump and control panel were used to actuate the cylinders. The load was applied to the building by the cylinders through a system of pads and whiffletrees. The load, scheduled to reach 190 per cent of design load, was applied in 10 per cent increments and stress and deflections recorded at each increment. Location of strain and deflection gages used in this test is shown in Figure 8 and 9, respectively.

RESULTS AND OBSERVATIONS

The test results and general observations made during the evaluation of the disaster shelter are covered in the following paragraphs.

Erection Studies

A summary of the manhours required to fabricate and erect the building in each of two erections and a breakdown of the manhours required in the second erection is given in Table 2. This table shows that a six man team can erect the disaster shelter in 32 manhours in the second erection.

The simplicity of the design, the use of the endwall frame as a templet for the interior A-frames, and the small number of parts made the initial erection of the building both fast and easy. This erection did reveal; however, several improvements that could be made in the design. Of primary concern was the difficulty encountered in driving the 2 x 4 stakes used for anchoring the bases of the A-frames. Not only were the stakes difficult to drive in the relatively soft soil of the erection site, but they also presented a problem of maintaining proper spacing between the A-frames. A mudsill was improvised in the field eliminating the stakes. This proved so successful that it was immediately incorporated into the final design.

Another change resulting from the initial erection study was the elimination of the angle cuts on the scabs and collar beams. It was determined that leaving the ends square still provided sufficient nailing area for an effective connection. The collar beams were lowered approximately 6-in. in order that 8-ft long members might be used, thus eliminating the special cutting to length of these members. Flexible covering material placed parallel with the rafters proved to be more effective since all joints under this scheme occurred over the rafters.

The second erection was made with new material incorporating all of the improvements resulting from the initial erection, see Figure 6 through 15 for erection procedure. The elimination of the angle cuts reduced the cutting time considerably. The reduction in erection time usually accomplished in repeated erections of a building were not realized in the second erection. This deviation from results from erection studies on other buildings is attributed to the simplicity of the design allowing an unusually low initial erection time. Pre-assembly of the A-frames by skilled or semi-skilled labor and assembly line methods of erection would give a material reduction in the erection time. It was noted that the use of stops and guides on the endwall frame "templet" speeded up the assembly of the A-frames considerably, see Figure 12. The use of lumber straight from the "yard" which varied in length from the design dimension as much as 1-in. had no adverse effects on the building. The only change or improvement revealed in this erection was that by running the long edge of the 4-ft by 8-ft rigid panels along the roof rafters greatly facilitates the attachment of this type of covering.

Weathertightness

The paper covered side and the rigid board covering with battens proved to be essentially weathertight with only minor leaks developing after 30 minutes of simulated direct downpour. The use of mastic would be advisable in areas of heavy rainfall but the building with dry joints would be adequate in areas of relatively light rainfall.

Structural Adequacy

The stresses and deflections recorded in the simulated wind load test are summarized in Table 3. All structural members were No. 1 common Douglas fir having an allowable stress of 1450 psi.

The wind loading was taken to 190 per cent of design and then discontinued as this was the maximum for all loadings scheduled for the building. At design load, a maximum stress of 705 psi tension comparied to the allowable of 1450 psi was recorded at point 2, see Table 4, and at 190 per cent of design a maximum stress of 1390 psi tension was recorded at the same point. The maximum recorded deflection at design load was a vertical movement of 0.65 in. at point 5, see Table 5, and at 190 per cent of design a maximum deflection of 1.28 in. was recorded at the same point.

Although not required under the criteria, a snow load was also simulated on the building. This load was carried to the equivalent of 32 lb per square foot without excessive stress or deflections.

CONCLUSIONS

As designed, this building has many desirable features which include the following:

1. Only lumber commonly stocked by lumber yards is used.

2. The building is easily and rapidly erected by unskilled labor.

3. The building is essentially weathertight.

4. The building frame and covering are structurally adequate, withstanding a 60 mph wind.

5. Single and double bunks and domestic style beds may be efficiently placed within the building.

6. Erection may be successfully made on sloping or uneven ground.

REFERENCES

1. RDB Project Card NY 500 002, Prefabricated Advance Base Building 15 May 1949.

2. Y & D Drawing No's 603,271 to 603,276 inclusive, "Disaster Shelter".

3. King, Harold P., "Development and Design of a Disaster Shelter", Final Report, 15 May 1953.

4. U. S. Naval Civil Engineering Research and Evaluation Laboratory Technical Memorandum M-038, BuDocks Design 40-ft by 100-ft Prefabricated Steel Utility Building, by R. A. Breckenridge and A. B. Bruck, 1 January 1952.

APPENDIX I (Continued)

7. FLOOR

No floor is required. Floor will be dirt or other expedients provided by the government at the erection site.

8. MATERIALS AND CONSTRUCTION

Materials used for the fabrication of this building should be readily available in large quantities. Alternative materials must be conceived for each component part. It is believed that steel, aluminum and other materials of a critical nature should be avoided. The walls and/or roofing materials should be of flexible nature which can be rolled, folded or otherwise compactly packed for shipment. Duck should not be considered.

9. LIFE EXPECTANCY

It is only required that materials used in this building be of such nature as to provide a minimum of three months use under the various conditions existing throughout the United States.

10. INSULATION

Provisions shall be made for the application of insulation to the interior of the buildings after the building is erected.

11. SIZE OF COMPONENT PARTS

All components of this building shall be of such a size and shape that they can be economically packaged for shipment by common carrier.

12. ERECTION

Design shall be such that erection may be readily accomplished by unskilled labor using a minimum of tools and no special handling equipment. Individual parts shall be such that they can be man-handled into place by a maximum of two men.

13. RE-ERECTION

Disassembly and re-erection is not considered essential for this building. However, the design should be such that maximum salvage of materials can be achieved with a minimum of effort.

14. FABRICATION

Design shall be such that the building can be fabricated by large numbers of existing firms. Designs requiring the use of specialized or comparatively rare types of machine tool or ship equipment should not be considered.

TABLE 1. MATERIAL REQUIRED FOR ONE DISASTER SHELTER

Item	Description	Amount Req'd
1. Lumber	Framing lumber	1110 BF
2. Roof & Wall Covering	4-ft by 8-ft rigid panel board	57 sheets
	battens (See Y & D Dwg. No. 603275)	352 Lin.ft.
3. Roof Cover	30-in. wide (min) flexible translucent (Waterproof material 48-in. wide preferred)	50 Lin.ft.
	Battens (See Y & D Dwg. No, 603275)	96 Lin.ft.
4. Window Material	48-in. wide flexible translucent waterproof material	20 Lin.ft.
5. Hardware-Rough	Nails-8d	30 lbs
	Nails-Roofing	35 lbs
6. Hardware-Finish	Hinges-Butts-Strap or Tee-2 pr for doors & 2 pr for ventilators	4 pr.
	Door Pull-any type	2 ea.
	Door Spring-any type	2 ea.
7. End Wall Ventilator	42-in. wide, 14 mesh screen	8 Lin.ft.
Alternate Covering (See D-20 Y & D Dwg. No. 603275)		
8. Roof & Wall Covering	Flexible waterproof paper or rolled roofing-27-in. wide (min)	900 Lin.ft.
	30 in preferred battens (See Y & D Dwg. No. 603275)	1100 Lin.ft.
9. Lumber	1-in. x 4-in. (additional ribbon for alt. cover)	96 Lin.ft.
10. End Wall Screen (If entry is screened)	28-in. wide (min) 14 mesh screen	175 Lin.ft.

Note:

Delete Item 2 if alternate Item 8 is used.
Delete 9 sheets of Item 2, all of Item 4, and 2 pair of hinges for ventilators of Item 6 if alternate 10 is used.

TABLE 1. MATERIAL REQUIRED FOR ONE DISASTER SHELTER

Item	Description	Amount Req'd
1. Lumber	Framing lumber	1110 BF
2. Roof & Wall Covering	4-ft by 8-ft rigid panel board	57 sheets
	battens (See Y & D Dwg. No. 603275)	352 Lin.ft.
3. Roof Cover	30-in. wide (min) flexible translucent (Waterproof material 48-in. wide preferred)	50 Lin.ft.
	Battens (See Y & D Dwg. No. 603275)	96 Lin.ft.
4. Window Material	48-in. wide flexible translucent waterproof material	20 Lin.ft.
5. Hardware-Rough	Nails-8d	30 lbs
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	Door Pull-any type	2 ea.
	Door Spring-any type	2 ea.
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10. End Wall Screen (If entry is screened)	28-in. wide (min) 14 mesh screen	175 Lin.ft.

Note:

Delete Item 2 if alternate Item 8 is used.
Delete 9 sheets of Item 2, all of Item 4, and 2 pair of hinges for ventilators of Item 6 if alternate 10 is used.

TABLE 2. SUMMARY OF ERECTION TIME STUDIES
These erections were made with 6-man erection team.

Item	Manhours
Entire Building	
1st Erection	40.0
2nd Erection	32.0
Components (2nd Erection)	
Cutting of framing lumber	4.0
Nailing frames together	5.0
Erecting frames ("A")	4.0
Exterior sheeting*	10.0
End Walls, doors and vent	9.0
Total	32.0

*Each type of exterior sheeting, flexible and rigid took approximately the same time.

TABLE 3. SUMMARY OF STRUCTURAL TESTS

The recorded values given in this table represent only liveload values. All values corrected to account for weight of test gear.

Item	Units	Wind Load
Design Loading	As noted	60 mph
Maximum Loading	As noted	84 mph
Load Increment	Per cent design	10
Stresses (Design Load)		
Tension		
Magnitude	psi	705
Location	no.	2
Compression		
Magnitude	psi	655
Location	no.	5
Stresses (Maximum Loading)		
Tension		
Magnitude	psi	1390
Location	no.	2
Compression		
Magnitude	psi	1305
Location	no.	5
Deflections (Design Loading)		
Vertical		
Magnitude	in.	0.65
Location	no.	5
Horizontal		
Magnitude	in.	0.51
Location	no.	4
Deflections (Maximum Loading)		
Vertical		
Magnitude	in.	1.28
Location	no.	5
Horizontal		
Magnitude	in.	1.09
Location	no.	4

TABLE 4. RECORDED LIVELOAD STRESSES ON THE FRAME OF BUILDING FOR WIND LOADINGS

1100 psi = allowable stress at design loading. Units = psi, + tension, - compression, $E_w = 1.6 \times 10^6$ psi for converting strain to stress. See Figure 8 for location of strain gages.

Point	Wind Loading Per Cent Design Load 50	100	190
1	+ 15	- 30	- 105
2	+310	+705	+1390
3	+ 50	+120	+ 240
4	- 40	- 95	- 190
5	-280	-655	-1305
6	0	- 50	- 80
7	+ 15	+ 15	+ 50
8	+ 15	+ 15	+ 55

TABLE 5. RECORDED LIVELOAD DEFLECTIONS FOR THE SIMULATED WIND LOADINGS

(Units - in.; See Figure 9 for location and positive direction of deflection gages).

Point	Wind Loading Per Cent Design Load 50	100	190
1	+.28	+.61	+1.16
2	+.10	+.23	+ .59
3	0	0	0
4	+.20	+.51	+1.09
5	-.27	-.65	-1.28
6	+.02	+.05	+ .09

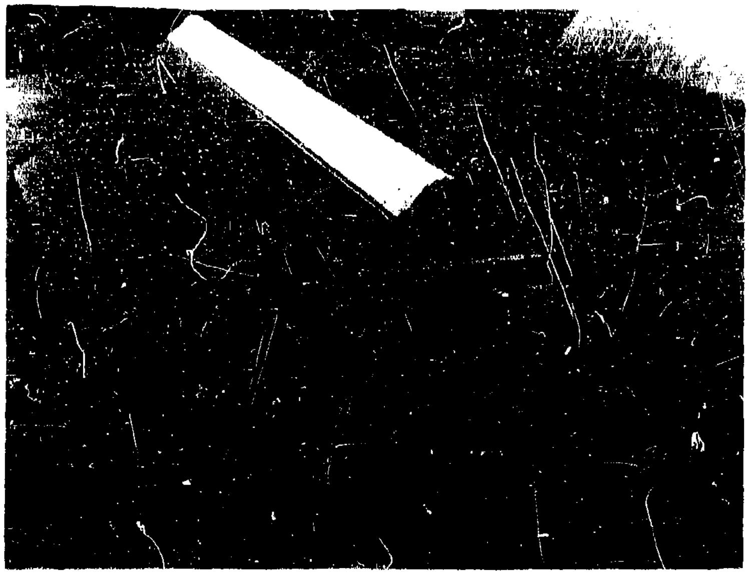

Figure 1. Disaster Shelter.

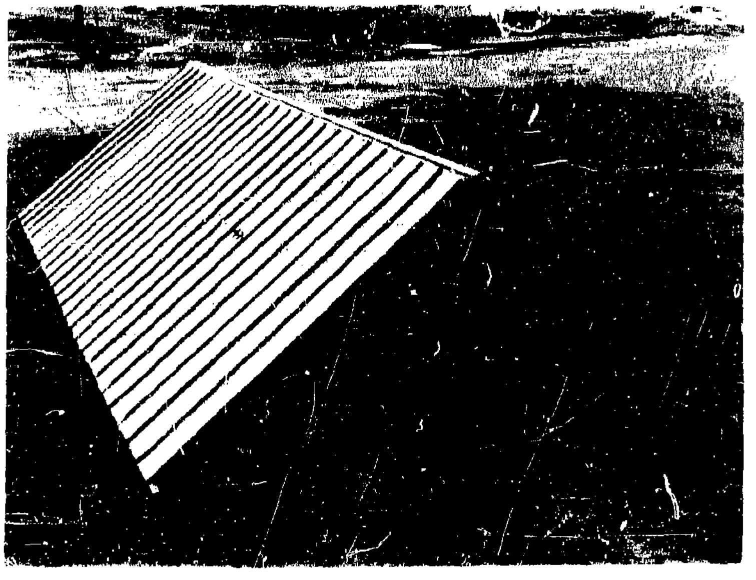

Figure 2. Flexible covering on building.

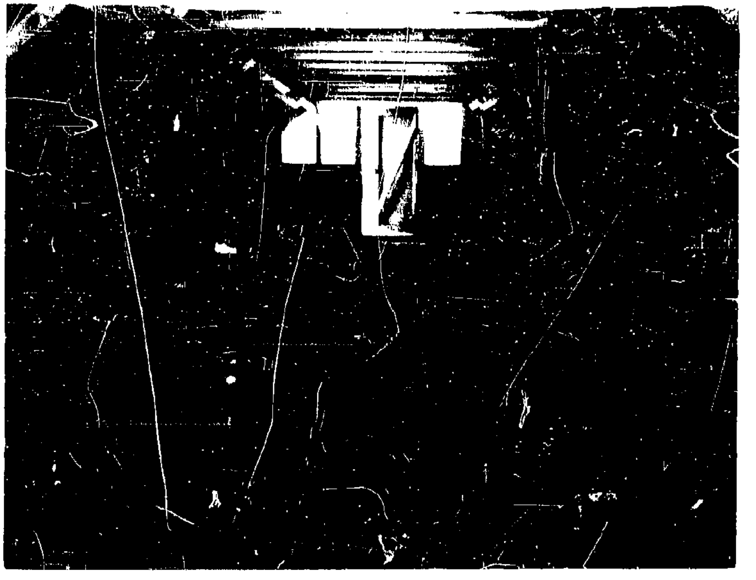

Figure 3. Single bunk arrangement in shelter.

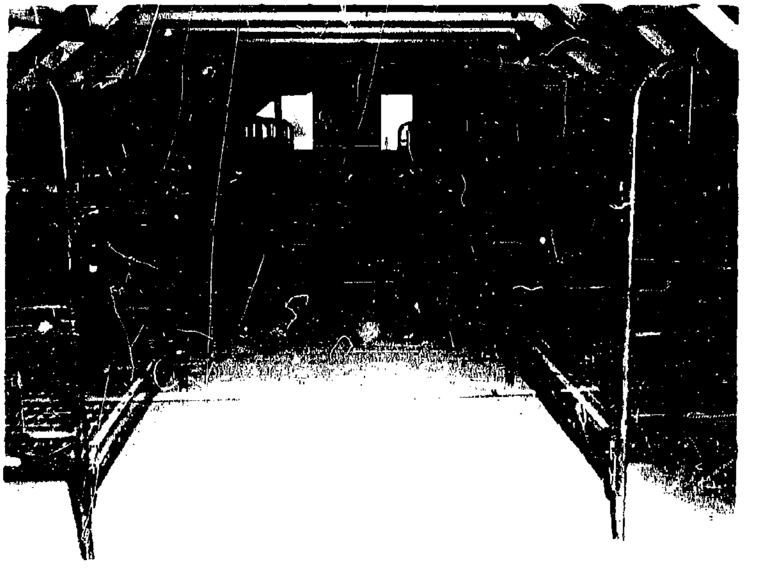

Figure 4. Double bunk arrangement in shelter.

Figure 5. Single bunk added between double bunk and wall.

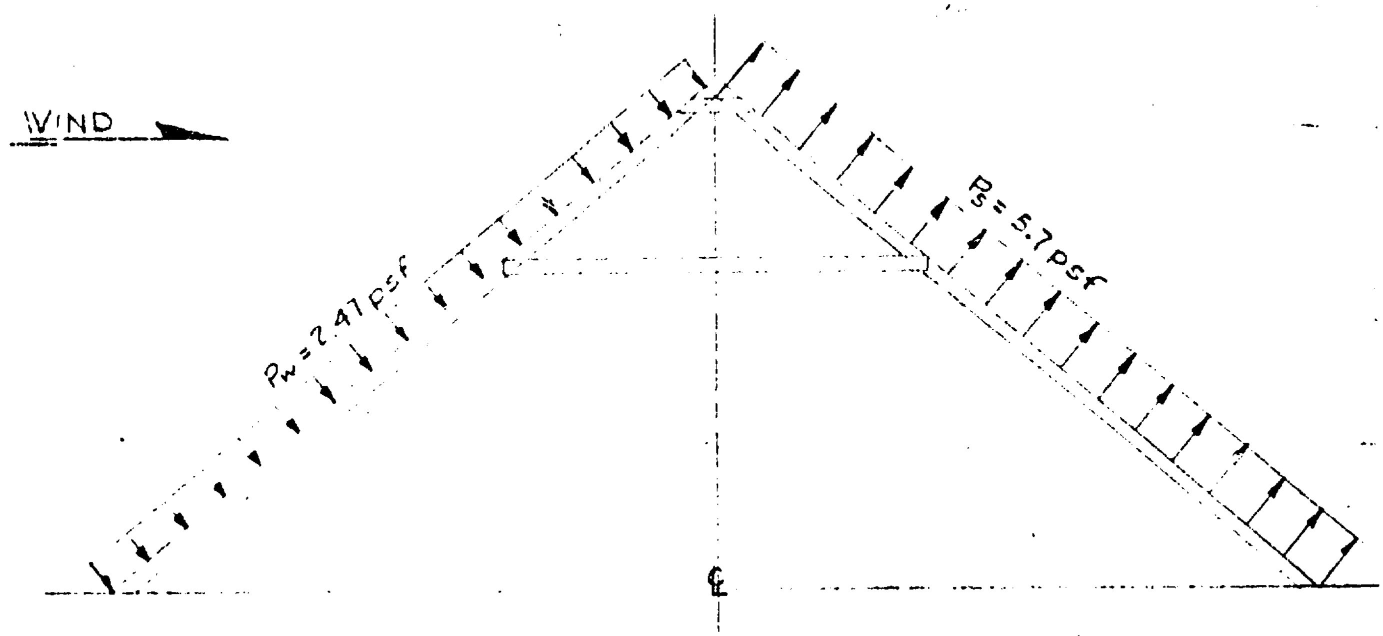

FIGURE 6. DESIGN WIND LOADING CONDITION

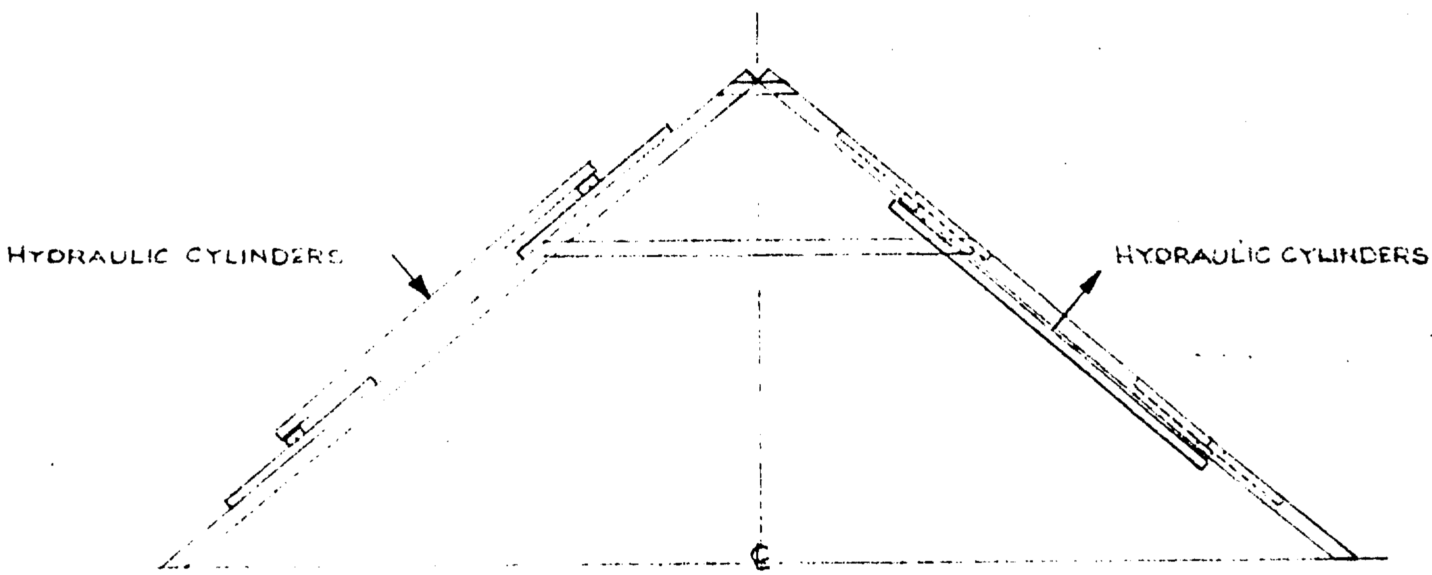

FIGURE 7. METHOD OF APPLYING SIMULATED WIND LOADING HYDRAULICALLY USING PADS

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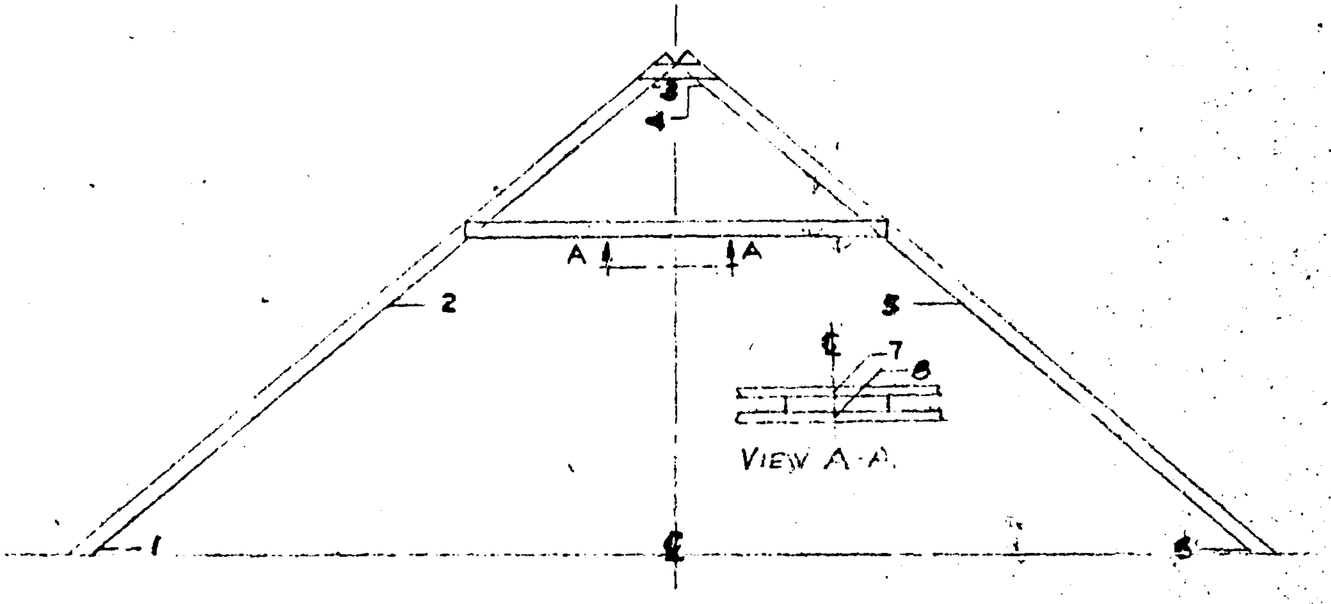

FIGURE 8. LOCATION OF STRAIN GAGES

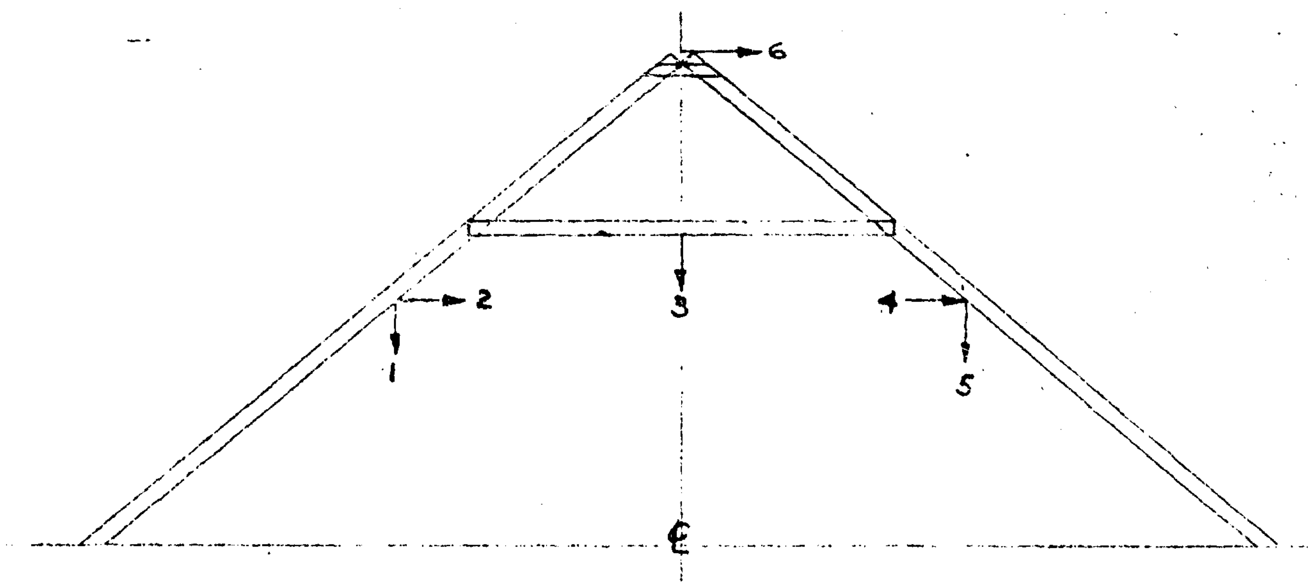

FIGURE 9. LOCATION OF DEFLECTION GAGES

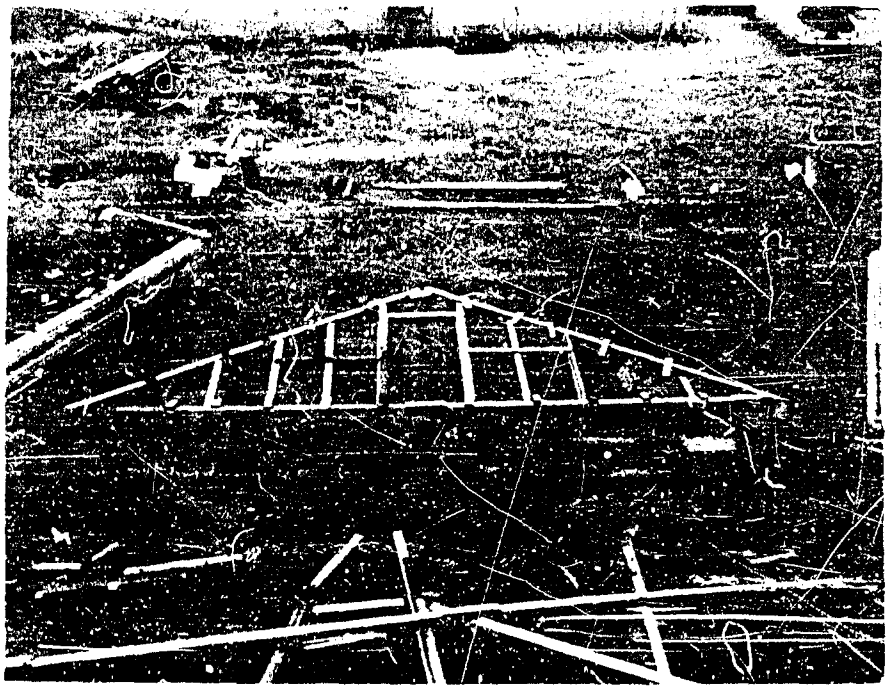

Figure 10. Endwall frame laid out prior to nailing.

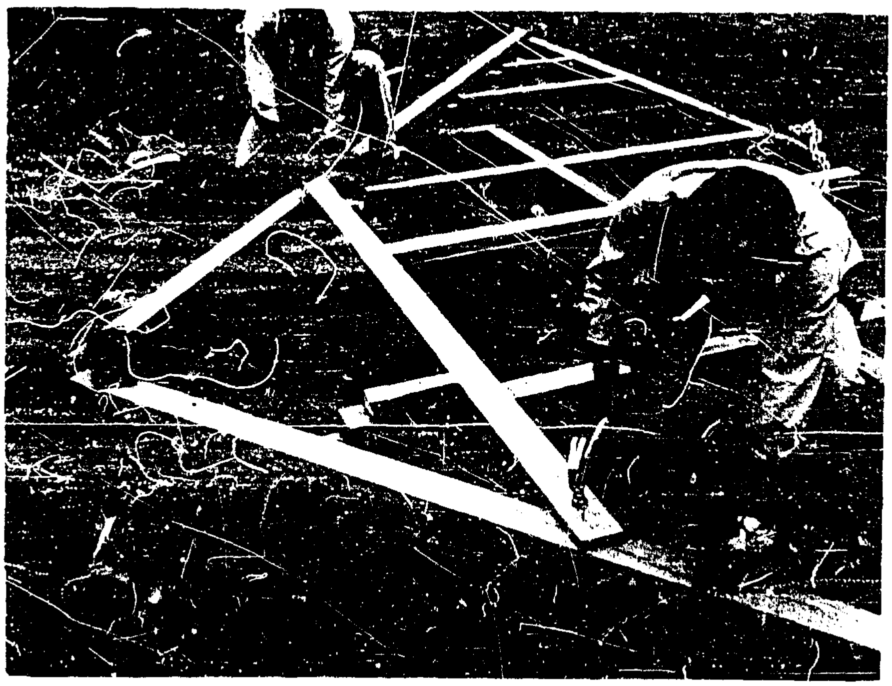

Figure 11. Assembling A-frames using endwall frame for templet.

Figure 12. Stops attached to endwall frame for A-frame assembly.

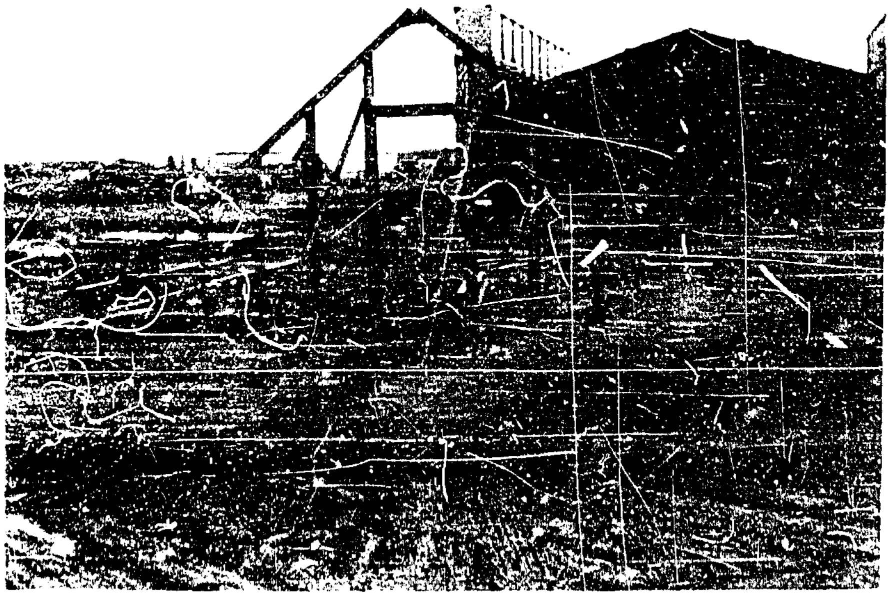

Figure 13. Endwall frame temporarily braced into position.

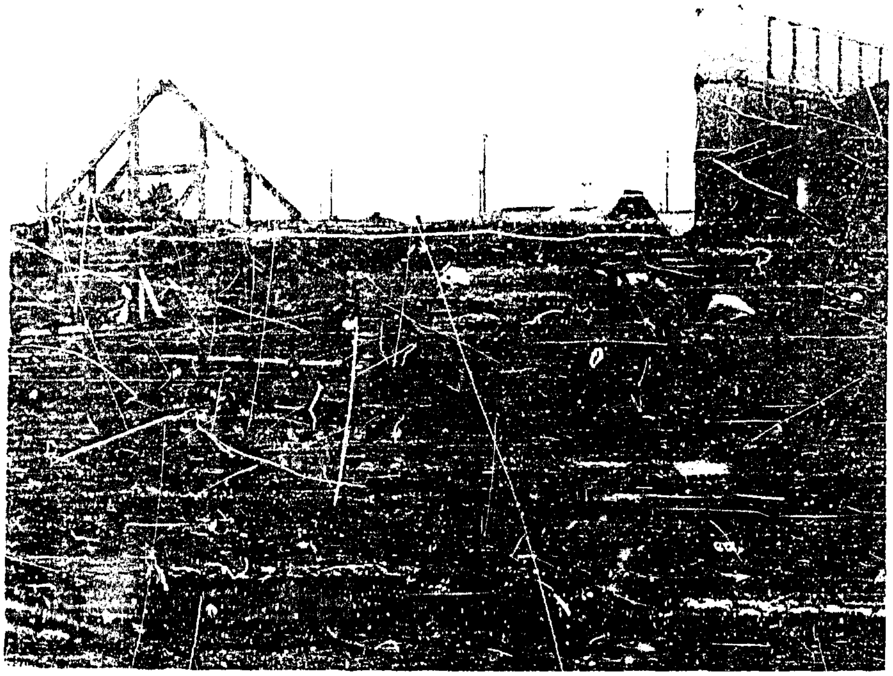

Figure 14. Mudsills and endwall frame.

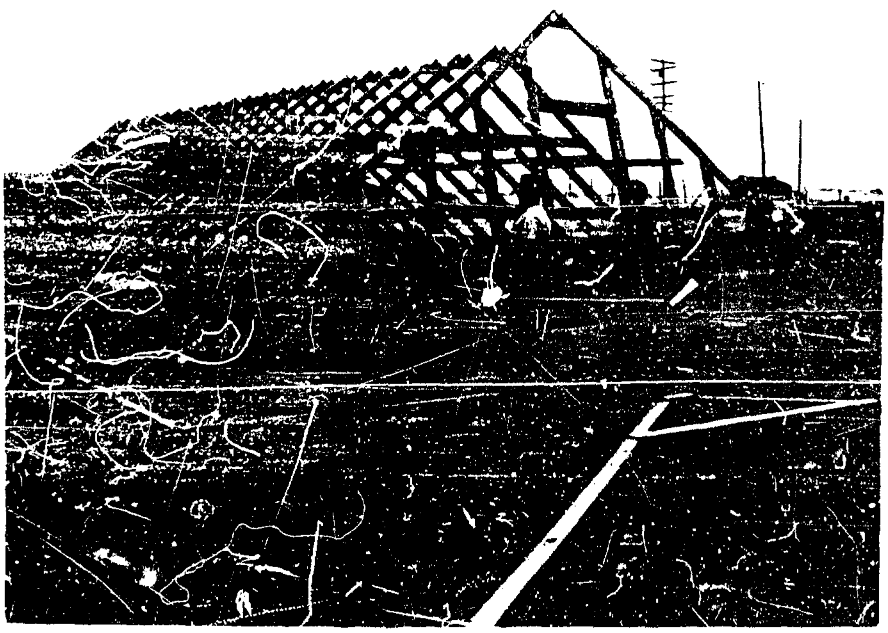

Figure 15. Placing second endwall frame into position.

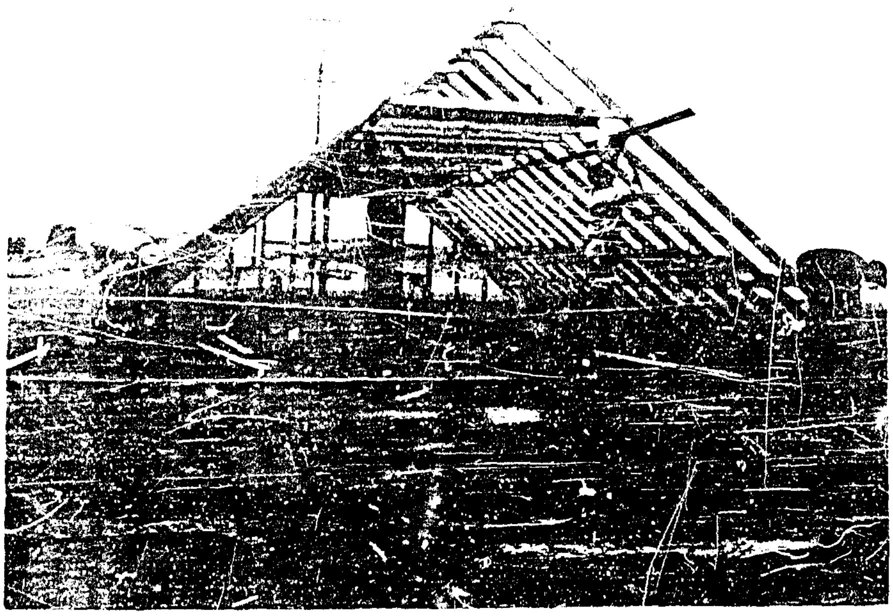

Figure 16. A-frames placed into position.

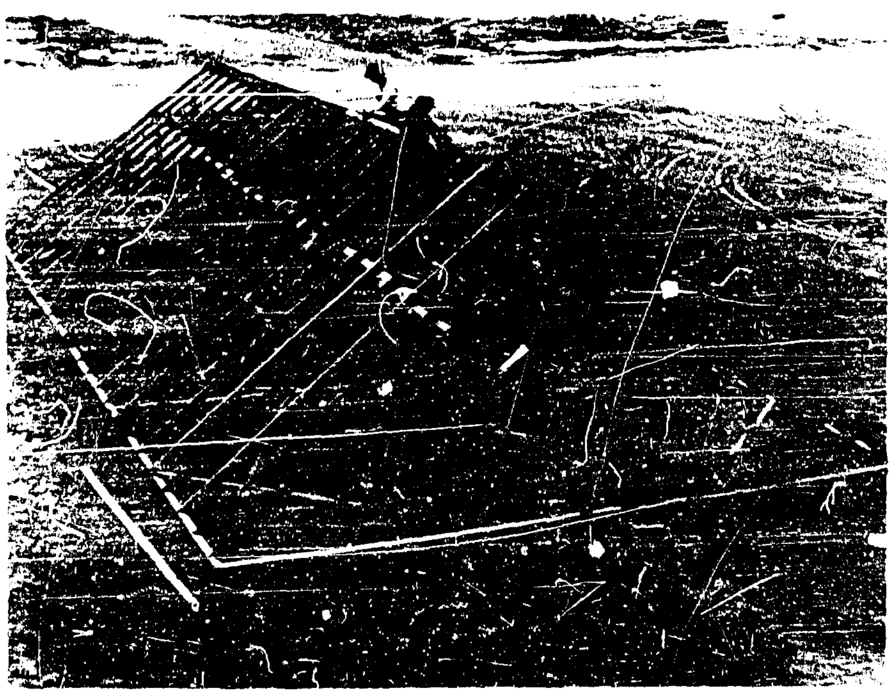

Figure 17. Completed framing. Ridge ledgers being installed.

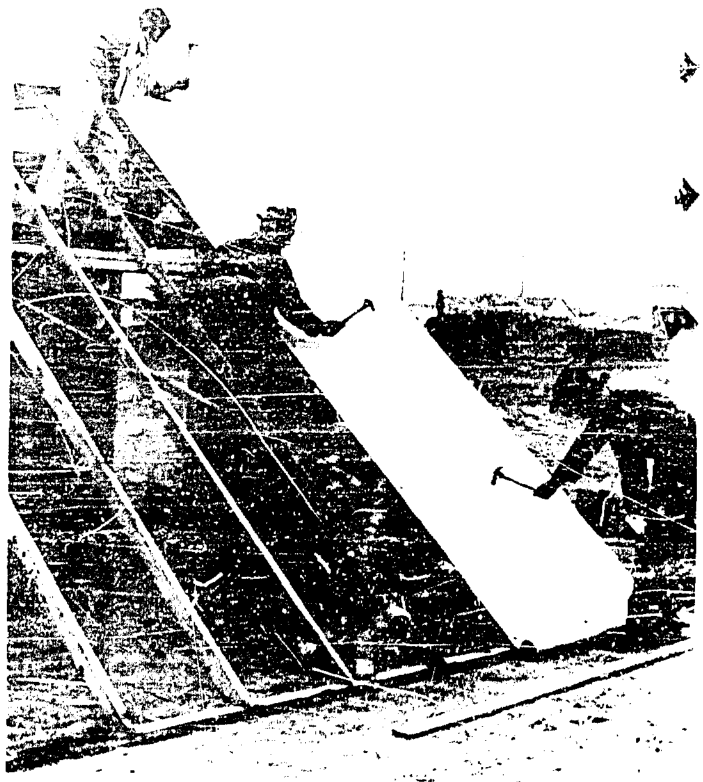

Figure 18. Placing flexible covering.

Figure 19. Placing rigid board covering.

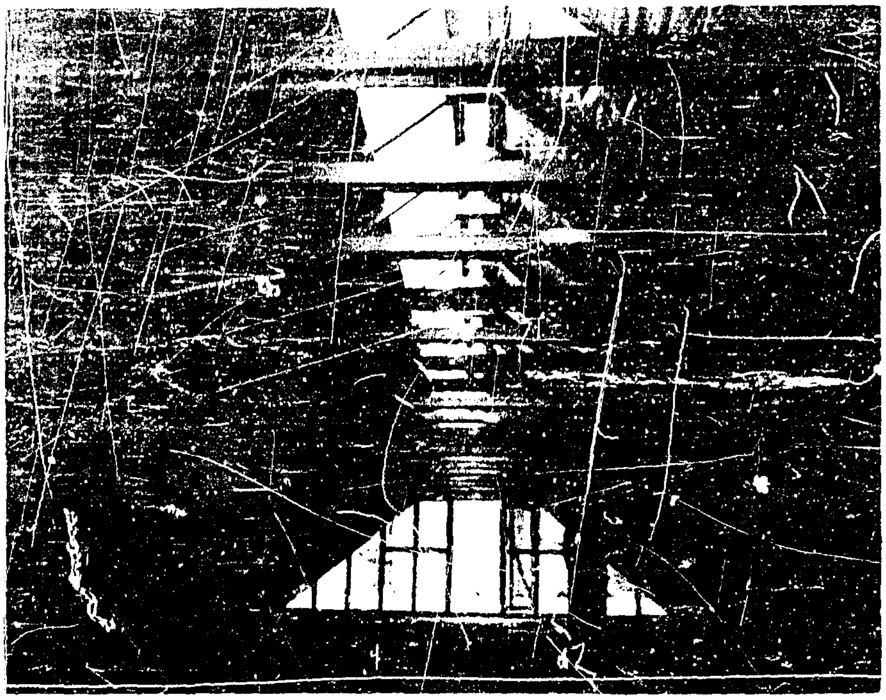

Figure 20. Interior view of completed structure.